# COMPRESSIVE BEHAVIOUR OF POLYETHYLENE TEREPHTHALATE (PET) AS PARTIAL COARSE AGGREGATE REPLACEMENT IN CONCRETE

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## ABSTRACT

In this developing world, the waste generated is gradually increased due to urbanization. Nevertheless, the solid waste in Malaysia is managed or disposed through landfill and partly to recycle. There is 35568 tons of waste being produced per day in Malaysia with the growth rate of 3.59% per year. In this rate of waste generation, the insufficient of landfill can become a significant problem in coming years. Therefore, recycle of solid waste is a compulsory act to prevent further destroying of environment and preserve the natural resources for the use of future generation. Waste accumulation can be solved by alternative solution such as replacement of aggregate by solid waste. The aim of this work is to determine performance of different percentage of Polyethylene Terephthalate (PET) as coarse aggregate replacement and suitability of plastic aggregate in concrete. The effects of natural aggregate and plastic aggregate in shape and behaviour were investigated. Test for slump, rebound hammer, compressive strength, heat absorption and water absorption were carried out to identify the suitability of plastic aggregate replacement. This study focused on the bottle neck of PET as coarse aggregate replacement and compressive behaviour of concrete with PET, varying the percentage of coarse aggregate replacement (10, 20, 30 and 40 vol%). The compressive strength is decreased as the plastic aggregate content is increased compared to conventional aggregate. This study presents an alternative way of recycling PET to reduce solid plastic waste and capacity of landfills.

# ABSTRAK

Dalam zaman pembangunan ini, pembandaran merupakan factor peningkatan sisa. Namun begitu, sisa pepejal di Malaysia digurus atau dilupus melalui tapak pelupusan dan sebahagian lagi adalah untuk mengitar semula. Terdapat 35568 tan sampah dihasilkan sehari di Malaysia dengan kadar pertumbuhan 3.59 % setahun. Dengan kandar pertumbuahn ini, kekurangan tapak pelupusan boleh menjadi satu masalah yang besar pada masa yang akan datang. Oleh itu, kitar semula sisa pepejal adalah amalan yang wajib untuk mencegah permusnahan alam sekitar dan memelihara sumber-sumber semula jadi untuk kegunaan generasi masa depan. Pembuangan sisa boleh diselesaikan dengan penyelesaian alternatif seperti penggantian agregat oleh sisa pepejal. Tujuan kajian ini adalah untuk mengidentifikasikan prestasi yang terbaik dalam peratusan Polyethylene Terephthalate (PET) yang berbeza sebagai pengganti agregat kasar dan kesesuaian agregat plastik di dalam konkrit. Kesan agregat semula jadi dan agregat plastik dalam bentuk dan ciri-ciri perlu diidentifikasi. Ujian kemerosotan, pemulihan tukul, kekuatan mampatan, penyerapan haba dan penyerapan air telah dijalankan untuk mengenal pasti kesesuaian penggantian agregat plastik. Kajian ini memberi tumpuan kepada leher botol PET sebagai pengganti agregat kasar dan ciri-ciri mampatan konkrit dengan pengubahan peratusan penggantian agregat kasar (10, 20, 30 dan 40 vol%). Kekuatan mampatan menurun semasa kandungan agregat plastik meningkat berbanding dengan agregat konvensional. Kajian ini membentangkan cara alternatif dengan kitar semula PET untuk mengurangkan sisa pepejal plastik dan kapasiti tapak pelupusan.

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## LIST OF SYMBOLS

| | |
|---|---|
| % | Percentage |
| mm | Millimeter |
| $N/mm^2$ | Newton per millimeter square |
| kg | Kilogram |
| N | Newton |
| °C | Degree Celsius |
| ∑ | Sum |
| w/c | Water to cement ratio |
| $mm^2$ | Millimeter square |
| min | Minute |
| µm | Micrometer |
| MPa | Mega Pascal |
| ± | Plus-Minus |

# LIST OF ABBREVIATIONS

| | |
|---|---|
| ABNT-NBR | Technical Standards Brazilian Association |
| ASTM | American Society for Testing and Materials |
| BS | British Standard |
| CEM | Certified Energy Manager |
| EN | European Standards |
| FPZ | Fracture Process Zone |
| MS | Malaysia Standard |
| NA | Natural Aggregate |
| OPC | Ordinary Portland Cement |
| PA | Plastic Aggregate |
| $PA_0$ | 0% of Plastic Aggregate |
| $PA_1$ | 10% of Plastic Aggregate |
| $PA_2$ | 20% of Plastic Aggregate |
| $PA_3$ | 30% of Plastic Aggregate |
| $PA_4$ | 40% of Plastic Aggregate |
| PET | Polyethylene Terephthalate |
| RILEM | Reunion International Laboratories Experts Material |
| SPI | Society of Plastic Industry |
| WPLA | Lightweight Aggregate |

# CHAPTER 1

# INTRODUCTION

## 1.1 BACKGROUND

Urbanization is a common phenomenon for developing country like Malaysia. In 2011, urban population of Malaysia is stated as 72.8 % of its total population (Central Intelligence Agency, 2014). This population rate leads to the flourish of construction sector. Malaysia Key Economic Indicator showed that the construction sector had preliminary record of 3.5 % in growth (Economic Development, 2011). The development of construction has increased the demand of aggregate as it's a raw material for concrete.

Concrete is a common type of construction material which produce by mixing of water, aggregate and cement in different ratio. The growth of demand in concrete is predicted approximately 18 billion tons by 2050 (Khoshkenari et al., 2014). Since the general formula of concrete is 1:2:4 which represent cement, fine aggregate and coarse aggregate, concrete consists around 85 % of aggregate. At this huge usage of aggregate, the increase of mining activity is inevitable. The current mining activities create unsuitability in environment and imbalance in ecologic. Diminution of mining activities is necessary to save the natural resources. Global concerns in the environment awareness also affect the construction concept in strategic planning to reduce environment impact (Henry & Kato, 2014).

In addition, the waste generated is gradually increased due to urbanization. There are few methods of disposal, such as incineration, landfilling and recycling (Albano et al., 2009). Nevertheless, the solid waste in Malaysia is managed or disposed through landfill and partly to recycle. There are 165 landfill areas operating and 35568 tons of waste is produced per day in Malaysia with the growth rate of 3.59 % per year (JPSPN, 2014). In this rate of waste generation, the insufficient of landfill can become a significant problem in coming years. Therefore, recycle of solid waste is a compulsory act to prevent the continuous on destroying environment and preserve the natural resources for the use of future generation (Environmental Protection Agency, 2014). Waste accumulation can be solved by alternative solution such as replacement of aggregate by solid waste.

In Malaysia, plastic waste is at the second highest rank which is 24 % out of total solid waste (The Star, 2012). Even in others countries, the waste of plastic is always within the rank of top five. Plastic waste includes containers, durable waste such as furniture, and non-durable waste such as diapers and medical devices (Solid Waste District, n.d.). Polyethylene Terephthalate (PET) is a type of polymer that mostly used to produce food and beverage containers. It comes with the SPI Resin Identification Code of 1. Recycling of PET is very common in worldwide. PET postconsumer resin is normally used for production of fiber, film and sheet (United States National Postconsumer Plastics Bottle Recycling Report, 2012).

The value of PET mostly falls back to the plastic production sector. The possibility of PET in replacing aggregate can develop a new market for PET postconsumer and also provide an alternative option for construction industry in material selecting. The suitability of the replacement of PET as coarse aggregate in concrete mixing is needed to be identified.

**Figure 1.1**: Plastic waste

Source: BioEnergy Consult

## 1.2 PROBLEM STATEMENT

The flourish of construction sector leads to the increase in demands of construction material such as cement and aggregate. The replacement of construction material by waste such as Polyethylene Terephthalate is a solution for the high demand of aggregate.

In concrete mixing, concrete is constituted by 60 % to 80 % of aggregate in volume and 70 % to 85 % of concrete in weight. However, aggregate is a non-renewable source. The continuous of quarrying activities is bringing the negative impact to the environment and shortage of aggregate. The replacement of aggregate is needed to reduce the impact of quarrying.

Polyethylene Terephthalate (PET) is a kind of plastic waste that is increasing directly proportional to human waste. Plastic is occupying 9.27 % in average global waste composition (Waste Atlas report, 2013). This problem is causing the insufficiency of landfill area in the coming years.

The replacement of aggregate by PET is a mutualism solution to solve both problems. The recycle of PET and reduce of quarrying activities can protect and preserve the natural environment.

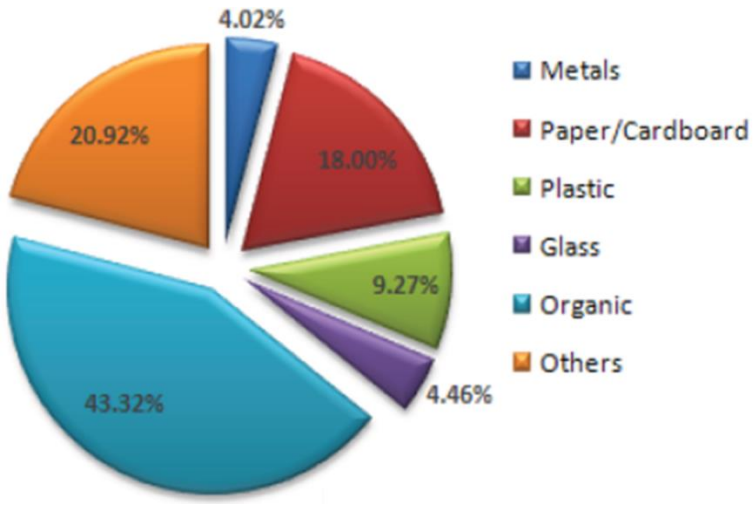


**Figure 1.2**: Average global waste

Source: Waste Atlas report, 2013

## 1.3 OBJECTIVE

Replacement of aggregate by Polyethylene Terephthalate (PET) can be a better option to reduce negative impact to environment if it achieves the same function as aggregate.

1. To identify the suitability of replaced aggregate in concrete.
2. To determine and improve the compressive strength of replaced aggregate in concrete.
3. To determine performance of different percentage of PET as coarse aggregate replacement in concrete.

## 1.4 SCOPE OF STUDY

In this study, certain percentage of Polyethylene Terephthalate (PET) is used to replace coarse aggregate in concrete mixing.

1. The bottle neck of plastic bottle is used and the diameter is fixed at 20 mm to 30 mm, the height is fixed at 15 mm to 25 mm.
2. A layer of polystyrene is filled into the bottle neck.
3. 0, 10 %, 20 %, 30 %, 40 % of Polyethylene Terephthalate (PET) is used to replace coarse aggregate in concrete mixing.
4. The concrete is designed as grade 25 by using Polyethylene Terephthalate (PET), granite, sand, Portland cement and water.
5. The size of the concrete is 100 mm x 100 mm x 100 mm.
6. The specimen is tested at the age of 1 day, 7 days and 28 days.
7. The tests carried out on fresh and hardened concrete are slump test, rebound hammer, compression test, heat absorption test and water absorption test.

## 1.5 RESEARCH SIGNIFICANT

Reuse of waste product such as Polyethylene Terephthalate (PET) as an aggregate in concrete mixing is a mutualism option for solid waste management and construction industry. It can reduce the negative impact to environment while supporting the development of construction industry. The research can give the advantage to industries, environment and mankind.

The significant of this study are:

1. Reduce the waste production and capacity for landfill.
2. Reduce the use of non-renewable aggregate and maintain the balance of ecosystem
3. Introduce waste product such as Polyethylene Terephthalate (PET) to replace aggregate.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 INTRODUCTION

This chapter presents review of the previous relevant literatures, which includes composition of concrete, compressive strength of concrete and aggregate replacement. In addition, this topic focuses on the replacement of waste material as aggregate in concrete mixing and the negative impact that created by plastic waste. Furthermore, the characteristic and properties of Polyethylene Terephthalate (PET) are discussed in this topic.

## 2.2 CONCRETE

Concrete is a composite of cement, aggregate and water in a suitable mix proportion. Its raw material has high availability and the characteristic of durability and able to form in many dimension gives it advantage as the primary material in construction (Khoshkenari et al., 2014). The development of country is the main factor of increasing of concrete usage especially in infrastructure systems (Henry & Kato, 2012). The dramatically increases of concrete caused the increase of quarrying which bring negative impact to environment.

The global environmental issue is highlighted in every industry and new technology is invented to reduce environmental impact. In Nordic countries, a center of green concrete is established in Denmark to face the challenges of environment. Meanwhile, Norway supported this action by creating the online database and documentaries for green concrete (Henry & Kato, 2012). The green technology

in production of concrete and construction is very popular and encouraged in construction sector. Besides, construction industry is affected by its sustainability issue. Basically, the environment impact comes from the construction and erection of buildings. There are few methods to reduce environment impact which are to increase the performance and lifetime of concrete (Müller et al., 2014). Concrete also has its sustainable advantages such as resource efficient, long span life and carbon absorption (Hooton & Bickley, 2014). The additional advantage of reduction in environmental effect is that it can increase the value of concrete in its sustainable advantage.

The direction of development in construction showed its potential in green technology. The new trend of green technology cannot be stopped especially where the natural resources is limited. Replacement of natural resources such as production of cement and aggregate is not a new topic in research finding in response to the environment concerns.

### 2.2.1 Cement

Cement is the main material in concrete mixing. The behaviour of concrete is influenced by composition of cement (Florea & Brouwers, 2012). Ordinary Portland Cement (OPC) is chosen in this study because it has the basic hydration process in concrete production (Potgieter-Vermaak et al., 2007). Sajedi & Razak (2011) suggested that the fineness of cement is the major factor for its quality especially contribution in compressive strength. In another words, the finer cement gives better compressive strength.

### 2.2.2 Aggregate

Durability of concrete is also one of the main concerns in construction industry. The destruction of concrete is mostly caused by degradation of concrete when it is exposed to freezing. In concrete mixing, aggregate is the contributor of durability of concrete which has chemical resistance and high density (Skripkiūnas et el., 2013). Fine and coarse aggregate constitutes the largest portion in concrete mixing. Type of aggregate used affects the mechanical properties of fresh and hardened concrete. The

depletion of natural aggregate widen the research of replacement aggregate in civil field (Zhang et al., 2013).

Fine aggregate has the role of filling the voids between coarse aggregate to act as workability agent. The voids determine the density and strength of concrete (Zhang et al., 2014). Coarse aggregate is the major determinant in the contribution of concrete durability (Zhao et al., 2012). Gonilho et al. (2009) concluded that the aggregate size and its water content affected concrete durability. However, most of the coarse aggregate is non-renewable sources which required quarrying for the production. There is necessary to find alternatives yet renewable aggregate to replace the non-renewable aggregate to maintain ecology balance.

## 2.3 COMPRESSIVE STRENGTH OF CONCRETE

Compressive strength of concrete is a fundamental in design. Contribution of cement fineness is undeniable. In addition, Hao et al., (2013) also found that increasing of volume fraction leads to high compressive strength. It means aggregate plays an important role in contribution of compressive strength. However replacement of recycled aggregate had substantial effects on compressive strength of concrete (Mukharjee & Barai, 2014).

Water to cement (w/c) ratio is also one of the influence parameter on the compressive strength (Albano et al., 2009). The smaller water cement ratio gives the better compressive strength. Meanwhile, Koenders et al., (2014) confirmed that the initial moisture content of aggregate influence the development of compressive strength. In the research, dry aggregate with smaller water cement ratio had higher compressive strength as shown in Figure 2.1.

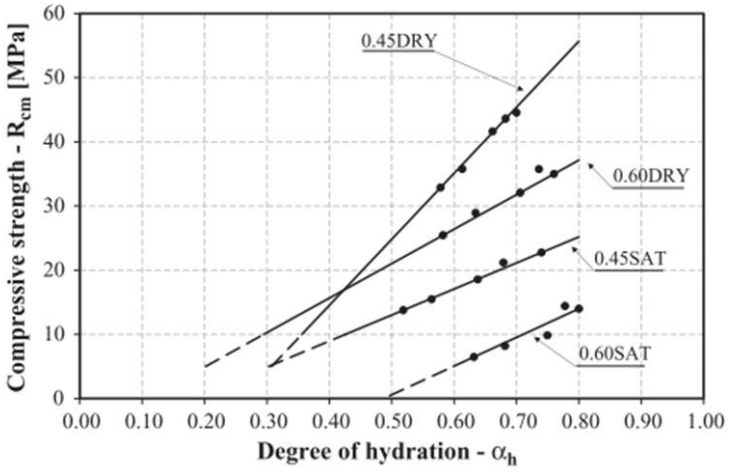


**Figure 2.1**: Graph of compressive strength against degree of hydration

Source: Koenders et al., 2014

## 2.4 PREVIOUS RESEARCH OF AGGREGATE REPLACEMENT

Natural aggregate is a non-renewable resource which its depletion of coming years cannot be avoided. The replacement of aggregate in research becomes a trend in research finding to reduce its quarrying effect to the environment. Aggregate contributes 85 % of volume in concrete. The large consumption of aggregate in construction industry creates burden to the environment especially the development of construction industry is flourish.

Besides, the reduction of carbon dioxide can be improved by using recycled concrete as aggregate (Hooton & Bickley, 2014). The environment negative impact can reduce by replace aggregate when the quarrying activity is reduced. Table 2.1 had tabulated the research done on replacement of aggregate.

**Table 2.1**: Previous Research In Aggregate Replacement Material

| No. | Type of aggregate replacement | Researchers |
|---|---|---|
| 1 | Concrete Waste | Mukharjee & Barai, 2014 |
| 2 | Steel Slag | Netinger et al., 2013 |
| 3 | Glass | Castro & de Brito, 2013 |
| | | Kou & Poon, 2013 |
| 4 | Chipped Rubber | Ganjian et al., 2009 |
| 5 | Marble Waste | André et al., 2014 |
| | | Uygunoğlu et al., 2014 |

### 2.4.1 Plastic waste as aggregate replacement

Plastic material is malleable. It's characteristic of low in cost and easy in manufacturing made it used in wide range of product such as packaging, healthcare and medical application. It has become an inseparable product in daily life. However, their waste and environmental management remain a big problem to society. The environmental issue of plastic waste is always highlighted in every sector. Its characteristic of long period biological degradation creates a challenge to mankind (Sánchez & Collinson, 2011).

Many studies were carried out since 1993 on the research of plastic waste in concrete. It was started with Bayasi and Zeng on the effect of polypropylene fibres on the properties of concrete. Later in 1997, Al-Manaseer and Dalal conducted the study on slump test with plastic aggregate (Siddique et al., 2008).

Choi et al., (2005) has conducted an initial study on the properties of concrete using waste PET bottle as aggregate replacement. From his investigation, lightweight aggregate made from plastic waste (WPLA) is used to replace fine aggregate in ratio. The result showed that compressive strength on 28 days decreased as the water cement ratio and replacement ratio increased. It achieved 21.8 $N/mm^2$ with water cement ratio of 0.53 and replacement ratio of 0.75.

Batayneh et al. (2007) conducted a study of plastics as a substitution of fine aggregate. In this study, 0, 5, 10, 15, 20 % of plastic is replaced in concrete with constant water cement ratio of 0.56. The result showed that concrete at 0 % of plastic substitution had the highest compressive, splitting and flexural strength. The relationship of the strength and percentage of plastic substitution is shown in Figure 2.2.

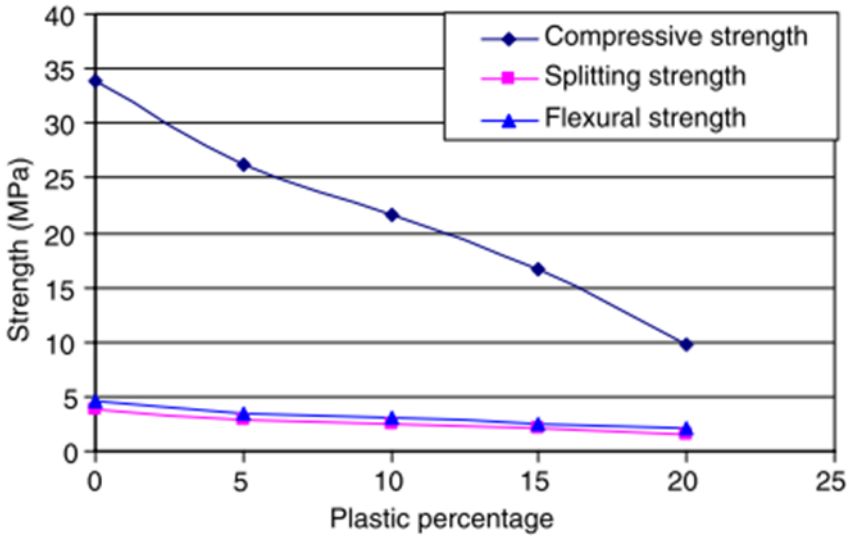


**Figure 2.2**: Relationship of the strength and percentage of plastic substitution

Source: Batayneh et al.,2007

## 2.5 PROPERTIES OF PET IN CONCRETE

Polyethylene Terephthalate (PET) has fastest consumption growth rate in worldwide (Bratek et al., 2013). It means that the growth is directly proportional to the waste of plastic. The main stream waste of PET came from food packages and soft drinks.

The properties of moisture barrier, high shatter resistance and exceptional gas made it suitable for the production of bottle (Gürü et al., 2014). Plastic aggregate created more free water and its properties of non-absorption water increased the slump.

Besides, it is lighter in weight compared to natural aggregate. This creates the potential of PET in development of lightweight concrete (Saikia & Brito, 2014).

The rheological properties such as flow and the compaction in concrete are changed by the addition of PET. Plasticity and consistency of fresh concrete decreased as the PET content increased (Albano et al., 2009). In addition, compressive strength increased proportionally to the resin content which also shown the characteristic of resin in filling the voids (Jo et al. 2008).

The shape of PET affected the properties of its in concrete. Saikia & Brito (2014) showed the shape of PET aggregate is affeceting the design of water cement ratio. In that research, the smooth and nearly spherical PET aggregate increase the slump value while reduces water cement ratio.

## 2.6 ENVIRONMENT ISSUE OF PLASTIC WASTE

The issue of waste management is the main concern in protecting environment especially plastic waste which has the characteristic of non-biodegration. Plastic waste contributes to land occuption and groundwater contamination issue to the environment (Yu et al., 2014). Argument on disposal method of plastic is never abated or satisfied by citizens.

An alternative solution is studied by many researches in the disposal and recyled due to the limited space and high cost of landfills (Zia et al., 2007). There are numbers of economic and environmental friendly solutions are sucessfully tested and conducted after years of research (Howard, 2002). The basic option for plastic waste management is mechanical recycled, landfill, incineration and feedstock recyclyed. Generally, mechanical recyclying is the best option (Rigamonti et al., 2014). Therefore, it appeared to have so many studies in plastic waste replacement of addition especially in the field of construction.

A mutual advantages is created while the field of construction has the environmental issue in emission of carbon dioxide in production of cement and quarying activities for aggregate. The problem can be solved by replacement or addition of plastic waste in concrete. A few of researches have been conducted on the plastic fiber replacing cement, plastic waste replace aggregate or plastic waste reinforce in the concrete. The table of replacement or addition of plastic waste in concrete is tabulated in Table 2.2.

**Table 2.2**: Replacement or addition of plastic waste in concrete

| No. | Type of plastic | Features | Researchers |
|---|---|---|---|
| 1 | Polyethylene Terephthalate | Replacement of aggregate in concrete | Silva et al., 2013 |
| 2 | Polyolefin and Polyethylene Terephthalate | Replacement of aggregate in mortar | Iucolano et al., 2013 |
| 3 | Polyethylene Terephthalate | Replacement of aggregate in Modified Asphalt | Rahman & Wahab, 2013 |
| 4 | Polyethylene Terephthalate | Reinforcement of concrete | Foti, 2013 |
| 5 | Polyethylene Terephthalate | Addition in cement | Mahdi et al., 2013 |

## 2.7 CONCLUDING REMARK

From the literature of this study, many researches on the replacement of plastic waste had been conducted especially replacement in fine aggregate. However, the replacement bottle neck of PET as coarse aggregate with a layer of polystyrene had not been done yet. It is important to determine the suitability of this type aggregate in concrete mixing.